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Vent Location Impacts on Building Compartment Fire under Natural Roof Ventilation

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Abstract

Numerical studies on impacts of vent location on building compartment fires under natural roof ventilation were conducted. The results indicated that there was no significant difference of the smoke filling among compartment fires with different vent locations. For compartment fire with a vent at the ceiling center, the oxygen concentration was much larger, and the gas temperature was lower. The pressure difference of the center vented compartment fire was larger than that of the corner vented fire, and the mass flow rate into the compartment was larger than out of the compartment from the perspective of the whole burning stage. For the two scenarios, the mass flow rates of the center vented compartment fire were much larger than that of the corner vented compartment fire. Cares should be taken when use the model for fires directly under the ceiling vent.

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Keywords: Natural ventilation, Ceiling vent, Mass flow, Vent flow

1. Introduction

Natural roof ventilation has been widely applied in building atriums, underground constructions, nuclear power plants and ship compartments [1, 2]. Due to the different vent flow pattern, compartment fire under natural roof ventilation behaviors differently from fires in traditional building compartments with vertical openings, such as doors and windows. Some studies have been conducted on fires in compartments under

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natural roof ventilation [3-5], and most of them devoted to compartment fires with a single fixed vent at the ceiling center or the corner. However, nearly no studies have been conducted on vent location impacts, which is surely a important issue for engineering design and performance-based fire protection design analysis. An obvious impacts of the vent location could be related to the vent flow. Epstein [6], Tan [7] and Cooper [8, 9] conducted some studies on the flow through ceiling vent with pressure and density differences by using brine/water modeling and theoretical analysis. However, the applicability of the results to real fire scenarios is still unclear.

Some experimental work [10-12] on ceiling vented or no vented compartment fire has been conducted in the enclosure fire research group in State Key Laboratory of Fire Science, including work on the impacts of vent location. However, the fuel would response to the thermal environment induced by the different compartment fires. Therefore, the comparison and the quantification of one single factor would be difficult. For instance, when we conducted the research of the vent location impacts, a constant heat release rate was hard to obtain. Under this circumstance, the results of the coupling effects could be provided, but the stand-alone influence of the vent location cannot be obtained. Nevertheless, the CFD technology provides a convenient route of studying those stand-alone influences. By using Fire Dynamic Simulator (FDS), a CFD code developed by National Institute of Standards and Technology (NIST) and solved numerically N-S equations for low-speed thermally-driven flow from fires, a constant heat release rate can be set and we can get some insights on the impacts of the vent location.

2. Scenarios

Figure 1 illustrates the schematic of the scenarios. The inner dimensions of the compartment were 3.00 m by 3.00 m by 1.95 m high. The dimensions of the ceiling vent were 0.60 m × 0.54 m and could be located at the ceiling center or the corner. A fire source with a constant heat release rate (HRR) of 100 kW was located at the floor center. As illustrated in Fig. 1, a thermocouple tree was used to measure the temperature rise in the compartment, so as to obtain the average gas temperature. Three oxygen probes, i.e., Port 1, Port 2 and Port 3, were positioned at a position halfway between the burner and the wall, and were set at the height of 1.70 m, 1.10 m and 0.60 m. The mass flow rate through the ceiling vent were also obtained.

The Large Eddy Simulation (LES) in FDS has been proved capable of predicting fire hazard in buildings. The governing equations can be referred to [13].

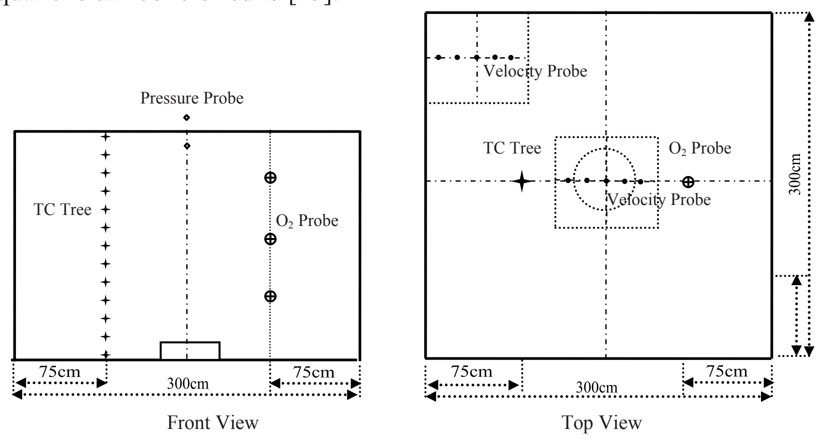

Fig. 1. The schematic of the scenarios

3. Results and discussion

3.1. Smoke filling process, oxygen concentration and gas temperature

It has been found that there was no significant difference of the smoke filling between the two cases. This means the entertainment rates of the plume under these two scenarios were almost the same, since the heat release rates of the two cases were all 100 kW and constant. The oxygen concentration in the compartment has been illustrated as Fig. 3(a). The oxygen concentration of the compartment fire with a vent at the ceiling center was much larger than that of the fire with a vent at the ceiling corner. This may be due to the different mass exchange rate through the ceiling vent. The gas temperature in the compartment has been shown in Fig. 3(b). It has been found that the gas temperature of the compartment fire with a corner vent was much higher than that of fire with a center vent. This was due to a more effective smoke ejection rate for the center vented fire.

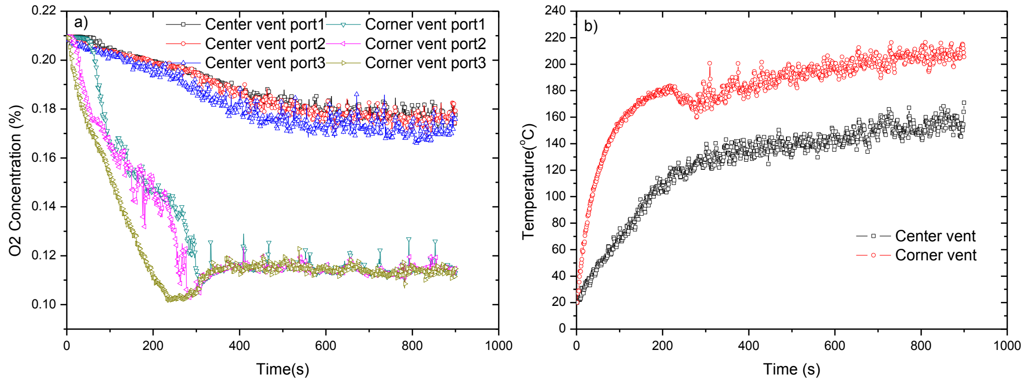

Fig. 2. (a) The oxygen concentration in the compartment; (b) The gas temperature in the compartment

3.2. Vent flow: pressure, velocity and mass flow rate

Figure 3 shows the difference across the ceiling vent. The pressure difference of the center vented compartment fire was larger than that of the corner vented fire. Since the pulsation of the pressure was strenuous, there were and bidirectional vent flow and intermittent unidirectional vent flow according to the calculation by the method from Cooper [8, 9]. However, from the mass flow rate in and out the compartment illustrated as Fig. 4, there were only bidirectional vent flow.

From Fig. 4, it can be seen that the mass flow rate into the compartment was larger than out of the compartment from the perspective of the whole burning stage. For the two scenarios, the mass flow rates of the center vented compartment fire were much larger than that of the corner vented compartment fire.

The mass exchange flow rate $\dot{m}_{v,max}$ was derived by Epstein [14] and have been widely accepted and applied by researchers, such as Cooper [8, 9]. and Chow et al [2].

$$\dot{m}_{v,max} = 0.055(4/\pi)\rho_0 A_v (gD|\varepsilon|)^{1/2} \tag{1}$$

where A_v is the area of the ceiling vent (m^2); D is the equivalent diameter of the ceiling vent (m); ε is Atwood number and can be expressed as $-2(T_g - T_0)/(T_g + T_0)$.

The calculated results of the corner vented compartment fire could be accepted, since Emmons [15] considered that the existing models on the horizontal vent flow are of “unknown accuracy in lieu of nothing”. In comparison, for the center vented cases, the results are far to be considered as useless. This indicated that cares should be taken when use the model for fires directly under the ceiling vent. When the fire was larger enough and the fire or smoke plume could directly rise out of the compartment, the existing models on the basis of the brine/water modelling might be unapplicable.

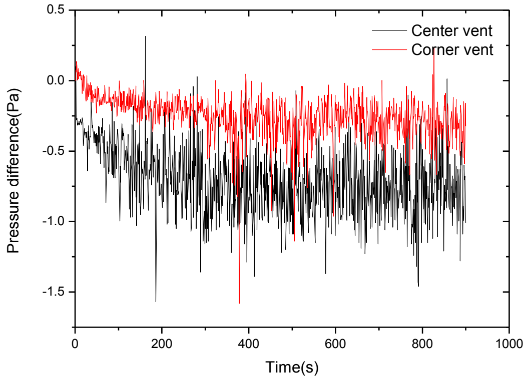

Fig. 3. The pressure difference across the ceiling vent.

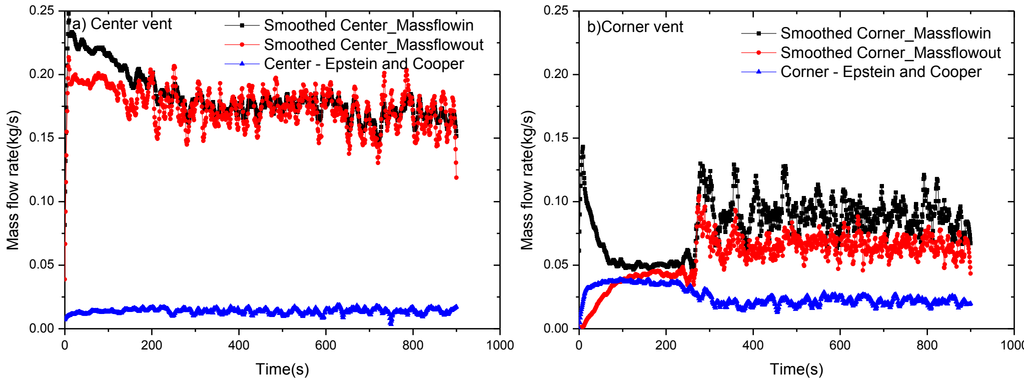

Fig. 4. (a) The mass flow rate through the center vent; (b) The mass flow rate through the corner vent

4. Conclusions

Numerical studies on the vent location impacts on the building compartment fire under natural roof ventilation were conducted. The major conclusions are summarized below:

1) There was no significant difference of the smoke filling among compartment fires with different vent locations if the heat release rates were the same. The oxygen concentration of the compartment fire with a vent at the ceiling center was much larger than that of the fire with a vent at the ceiling corner. It has been found that the gas temperature of the compartment fire with a corner vent was much higher than that of fire with a center vent.

2) The pressure difference of the center vented compartment fire was larger than that of the corner vented fire. The mass flow rate into the compartment was larger than out of the compartment from the perspective of the whole burning stage. For the two scenarios, the mass flow rates of the center vented compartment fire were much larger than that of the corner vented compartment fire. Cares should be taken when use the model for fires directly under the ceiling vent.

It should be noted that the numerical study by FDS cannot provide the fuel response effect of the ceiling vent size, which should be decided by experiments or chemical kinetics modelling.

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